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David H. Lax
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VIA Overnight Mail
June 10, 1999

attn: Terry Newell
MOBILE6 Review Comments
US Environmental Protection Agency
Assessment and Modeling Division
2000 Traverwood Drive
Ann Arbor, MI 48105

Re: EPA document no. M6.EVP.004, dated February 1999 and entitled *Update of Hot Soak Emissions*

Dear Mr. Newell:

The American Petroleum Institute (API) appreciates the opportunity to comment on the referenced document (M6.EVP.004) which proposes updated algorithms for modeling hot soak emissions as a function of Reid vapor pressure (Rvp) and ambient temperature based on "real world" test data collected after the release of MOBILE5a.

API strongly recommends that the proposal outlined in M6.EVP.004 be discarded.

To be quite frank, M6.EVP.004 ranks as one of the most fundamentally flawed assessments ever to be released in relation to a MOBILE model update. One of the most basic tenets of good science is to test prevailing theories of natural and physical processes through the application of sound, empirically derived data. It is by this means that existing theory is validated, discarded, updated or otherwise altered and improved. By this standard, the analysis by ARCADIS Geraghty & Miller (ARCADIS) that is contained in M6.EVP.004 fails on three counts:

1. It assumes *a priori* that the MOBILE5a hot soak factors and temperature correction adjustments represent scientific "truth" by constraining the proposed factors to be equivalent to those in MOBILE5a at 9.0 psi Rvp at all temperatures. These assumptions are made even though data from real world programs sponsored by EPA and Auto/Oil suggest significant revisions in a number of cases.

2. It relies in part on fabricated data points calculated from MOBILE5a hot soak equations. ARCADIS adds these fabricated data to the "real world" hot soak database because it deems the latter to exhibit trends in hot soak emissions versus Rvp for some vehicle classes that are "intuitively incorrect."

3. It relies upon statistical database analysis techniques that do not appropriately weight the observed emissions measurements to account for the fact that some vehicles in the real world test programs were tested multiple times under the same sets of conditions. This suggests that the authors of M6.EVP.004 were either unfamiliar with the nature of the underlying hot soak emissions databases or they simply disregarded the erroneous consequences of the approach chosen to conduct the statistical analysis.

We are not aware of any reason to support the notion that the MOBILE5a hot soak emission factors at 9 psi Rvp should be held inviolate. The adoption of such an assumption is equivalent to refusing to consider the weight of new data generated by both the real world emissions test programs and the non-real world (e.g., EPA emission factor) test programs that have been conducted since the release of MOBILE5. This is clearly a waste of good information and we are baffled by this posture. If EPA has a reason for insisting that the updated MOBILE6 hot soak factors match the MOBILE5 factors at 9 psi Rvp, then that reason should be clearly stated in M6.EVP.004.

In addition, the fabrication of data to support an assessment is, quite simply, without merit, inappropriate and well outside of the bounds of good, sound and credible science. We are left to wonder if the authors of M6.EVP.004 might not have arrived at different results had they bothered to investigate <u>why</u> the real world data which they analyzed showed the “intuitively incorrect” trend of increasing hot soak emissions with decreasing Rvp for some vehicle categories. (There is no evidence that this was done in M6.EVP.004.) This type of action is a disservice to both EPA and to all of the other MOBILE6 stakeholders.

These points and others are discussed in detail in the enclosed analysis of M6.EVP.004 that was prepared for API by Sierra Research, Inc. (Sierra). Sierra notes in particular that the methodology proposed by ARCADIS cannot be implemented with the EPA and Auto/Oil real world databases alone. These programs encompass a very narrow range of Rvp levels which provides very little scale across the measured emission levels of the test vehicles. This makes the task of predicting Rvp effects on hot soak emissions very difficult. Consequently, Sierra recommends an alternative approach which is to: (a) use the real world data to develop revised baseline hot soak emission rates, (b) use other additional emission factor test program data collected since the release of MOBILE5 to develop revised RVP and temperature correction factors, and (c) apply these factors to the aforementioned baseline emission rates.

Sierra illustrates the results of an application of this recommended methodology using data that were readily available to it. As shown in Figure 4 of the enclosure, Sierra’s approach yields a closer match between the modeled results and the real world data than that observed for the hot soak factors proposed in M6.EVP.004.

In summary, API has serious concerns about the hot soak emission factor methodology outlined in M6.EVP.004. That methodology should be discarded and EPA should adopt the approach described by Sierra Research in the enclosure.

API would be happy to offer assistance in performing some of the additional analyses that we have referenced in these comments, if EPA so desires. Please do not hesitate to contact me if you have any questions about this material or any of the comments made above.

Cordially,

David H. Lax

encl.

cc: Lois Platte, EPA (w/ encl)
Phil Heirigs, Sierra Research (w/o encl)

June 8, 1999

Memo To: David H. Lax
Senior Environmental Scientist
American Petroleum Institute
1220 L Street, NW
Washington, D.C. 20005-4070

From: Philip Heirigs

Subject: Review of the EPA/ARCADIS Report, "Update of Hot Soak Emissions"

At your request, we have performed a review of the report "Update of Hot Soak Emissions," which was prepared by ARCADIS Geraghty & Miller (ARCADIS) under contract to the U.S. Environmental Protection Agency (EPA). This report, which was posted on EPA's MOBILE6 Internet web site for review and comment, presents the results of an analysis of "real world" hot soak data that were collected after the release of MOBILE5a. (These data were collected in test programs sponsored by EPA as well as testing conducted as part of the Auto/Oil program.) Presumably, EPA intends to use the results of this study to form the basis of changes to hot soak emissions estimates in the MOBILE6 model. As outlined in the body of this memorandum, however, we have serious concerns about the analytical methodologies employed by ARCADIS to generate revised hot soak estimates for MOBILE6. The following issues are of most concern:

1. The use of an approach in which ARCADIS fabricated data points calculated by MOBILE5a hot soak equations and added those to the "real world" hot soak database because the emissions versus Reid vapor pressure (Rvp) trends observed in the "real world" data for some model-year and technology groups were "intuitively incorrect."

2. The application of a constraint that the revised factors had to match the MOBILE5a factors at 9.0 psi Rvp (at all temperatures). This prevented any meaningful revision to the hot soak emission rates, even though the real-world data support significant revisions for a number of technology and model year groups.

3. Data from vehicles tested multiple times over a range of Rvps and temperatures were treated as separate data points in the ARCADIS analysis. (These vehicles <u>were not</u> part of the real-world hot soak programs.) This has the effect of assigning more influence to vehicles with multiple test scores relative to vehicles that were tested only once. It would have been more appropriate to generate a

mean hot soak score for vehicles tested multiple times (or only use the score best matching the Rvp and temperature conditions of the real-world hot soak programs) before generating regression equations that are used to estimate fleet-average emissions.

4. Hot soak emission results from fuel-injected vehicles in the real-world databases were corrected to account for in-use fuel tank level using the adjustment from MOBILE5a. The MOBILE5a-based adjustment is applied to translate the 40% fill level required in the FTP to a nominal 55% fill level observed in-use. However, ARCADIS apparently failed to recognize that the real-world hot soak programs tested vehicles with the fuel level they had when recruited for testing. Hence, an adjustment for fuel tank level is not necessary in this case, provided the distribution of fuel levels in the test programs adequately reflects in-use conditions. (That was not investigated in the ARCADIS report.)

As described in Sierra's December 1997 report on real-world evaporative emissions,[*] the hot soak data collected in the EPA and Auto/Oil programs did not span a very broad range of Rvp conditions. In addition, because each vehicle was tested only once in these programs, the impact of Rvp changes on hot soak emissions cannot be accurately predicted because vehicle-to-vehicle variability can mask emissions effects that would be expected from Rvp changes.[**] Thus, although these new data provide a wealth of information on hot soak emissions at the temperature and Rvp conditions observed in those programs (i.e., summertime in Phoenix, Arizona), extrapolation to other conditions cannot be accomplished using that database alone. As a result, it would be more appropriate to use the real-world data to generate revised base emission rates for hot soak emissions, and then use the existing MOBILE5a temperature and Rvp correction factors to extrapolate those results to other conditions. Better yet, revised temperature and Rvp correction factors could be developed from additional data collected by EPA since the release of MOBILE5. (These data were collected over a fairly broad range of temperature and Rvp.) A proposed approach for this alternative is presented below.

In short, our recommendations are as follows:

- The analysis prepared by ARCADIS to support revisions to MOBILE6 hot soak emissions estimates should be discarded;

- The real-world data should be used to develop revised <u>baseline</u> hot soak emission rates; and

- The additional data collected since the release of MOBILE5 should be used to develop revised Rvp and temperature correction factors to be applied to the baseline emission rates developed from the real-world data.

If you have any questions regarding the information presented below, or if you would like any additional analyses, please call me or Bob Dulla at (916) 444-6666.

Review of MOBILE6 Proposal

Summarized below is a description of the data and methodologies used by ARCADIS to generate proposed hot soak emissions estimates for MOBILE6, along with Sierra's comments on those methodologies. Consistent with recent EPA analyses of evaporative emissions data, the data were first stratified into a gross liquid leaker category and a non-gross liquid leaker category. From that point, pressure/purge status was used as a broad category to evaluate data from the non-gross liquid leakers.

Available Data - The primary sources of data for this analysis included two "real world" hot soak test programs conducted in Phoenix, Arizona. The first of these, conducted in the summer of 1993, was performed as part of the Auto/Oil Air Quality Improvement Research Program (AQIRP) and included testing of 299 vehicles. The second, sponsored by EPA, was conducted in the summer of 1995 and included testing of 181 vehicles. Both programs used a test protocol in which the vehicle was recruited from an I/M lane, was driven on a road route selected to simulate the LA4 driving cycle, and then was placed in a SHED for hot soak emissions measurement. Tank fuel was used for this testing, and the SHED temperature was stabilized to the ambient temperature recorded at the start of the on-road preconditioning drive. These data were previously analyzed by Sierra in its report to API on real-world evaporative emissions.[*]

According to the ARCADIS report, a smaller number of additional vehicles were tested by EPA in follow-up test programs; these data were also included in the ARCADIS analysis. A review of Table 2 of the ARCADIS report, however, reflects that the follow-up testing amounted to an additional 150 vehicles being added to the total database (i.e., a total of 630 vehicles is cited in that table). This clearly does not reflect "smaller numbers of vehicles" as described by ARCADIS. We checked with EPA staff to get a better idea of the nature of the additional testing, and we were provided a spreadsheet containing the data that ARCADIS used in its analysis. A review of those data indicated that ARCADIS appears to have used data from vehicles that were tested multiple times. This includes vehicles that were subject to two different preconditioning procedures in the 1995 EPA hot soak study (i.e., some vehicles in that study were subjected to two on-road "LA4" preconditioning cycles in addition to the standard test protocol that called for a single on-road "LA4"), as well as vehicles that were tested over multiple Rvp and temperature combinations.[*] However, no attempt was made to account for the unbalanced nature of this data set. In fact, it appears that ARCADIS may not have been aware that some vehicles were tested multiple times, since the report continually refers to "the 630 vehicles tested." This is a concern because vehicles that were tested multiple times are being weighted too heavily relative to those vehicles (i.e., those in the "real world" database) that were tested only once.

We have serious concerns about mixing the data from the "real world" testing (i.e., the 1993 Auto/Oil AQIRP and 1995 EPA hot soak studies) with the additional data from the supplemental EPA test programs. That is because different test procedures were used for preconditioning, and vehicles in the supplemental EPA programs were tested multiple times over different Rvp and temperature combinations. In addition, there was relatively little Rvp variation in the "real world" studies. In fact, Auto/Oil analysts found that attempts to correlate hot soak emissions with fuel vapor pressure did not yield any significant relationship, and they concluded this was partially a result of the limited range of Rvp sampled.[*] Similarly, Sierra concluded that the real-world data could be used to establish revised baseline hot soak emission rates, but could not be used to develop Rvp and temperature corrections.

Gross Liquid Leakers - The first stratification that ARCADIS made to the data was to identify gross liquid leakers, which were defined as vehicles with liquid leaks resulting in hot soak emissions of 10 grams per test or more. As discussed above, EPA has made this distinction in some of its more recent analyses of evaporative emissions data. From a technical perspective, this approach makes sense because liquid leakers would not be expected to respond as much to temperature and Rvp changes as would vehicles with uncompromised control systems.

Overall, the real-world database that ARCADIS analyzed contained 17 liquid leakers, 9 of which fell into the gross liquid leaker category. These 9 vehicles consisted of two carbureted vehicles (mean hot soak emissions of 14.6 grams per test) and seven port fuel injected (PFI) vehicles (mean emissions of 57.8 grams per test). ARCADIS has suggested that these results be used to reflect leaks from carbureted and PFI vehicles, respectively, stating that it is reasonable to expect that fuel-injected vehicles would have higher liquid leak emissions because they operate under higher fuel pressures.

ARCADIS goes on to suggest that since the operating pressures of throttle body injection (TBI) vehicles is lower than for PFI vehicles, emissions from TBI liquid leakers would be roughly half that of PFI vehicles (citing the Bernoulli equation, which is generally used to describe flow through pipes, to support this contention[*]). However, we have several concerns with that approach:

- It assumes that all liquid leaks occur between the fuel pump and the pressure regulator;

- It suggests that a pressure differential is maintained throughout the duration of the hot soak (which would not be the case if there was a leak in the line, i.e., the pressure would bleed off); and

- It ignores the fact that gross leaks as a result of injector leakage could actually be more severe for a TBI vehicle because the injector(s) are typically upstream of the throttle plate.

Because of the sparsity of data on liquid leakers, it is most appropriate to simply calculate a mean emission rate and use that result for all technologies (including TBI) unless it can be definitively determined that the leak is related to a specific fuel-delivery component that exists on one technology but not the other.

One of the real challenges in modeling hot soak emissions will be to obtain sufficient data with which to estimate the in-use occurrence of gross liquid leakers. (In-use frequency was not addressed in the ARCADIS report.) Data on liquid leakers collected by Automotive Testing Laboratories (ATL) in late-1997 and early-1998[*] should be very helpful to EPA in translating the hot soak emissions estimates from gross liquid leakers into in-use projections.

For vehicles that do not have gross liquid leaks, an approach was used in which vehicles were first segregated by evaporative system functional check results. Regression equations were then developed that use Rvp and temperature to predict hot soak emissions for pressure test failures, purge test failures, and pressure/purge passing vehicles. That methodology is described as follows.

Pressure Test Failures - ARCADIS indicated that 80 of the 630 vehicles in their database were pressure test failures. (More correctly, 80 of the 630 tests were from vehicles failing the pressure test.) For pressure test failures, all data were combined because there were not enough data to support an analysis by fuel system type. These data were then adjusted to a 95°F basis using the MOBILE5a hot soak adjustment equation; i.e.,

$$HS_{Adj} = HS * \exp(1.774+0.05114*(95-82)) / \exp(1.774+0.05114*(T-82))$$

where HS_{Adj} is the 95°F adjusted hot soak value, HS is the tested hot soak value, and T is the test temperature. The data from fuel-injected vehicles were then divided by 0.88, which is the factor in MOBILE5a that accounts for differences between in-use and FTP fuel tank levels. However, because the "real world" data were based on the fuel tank levels of the vehicles as they entered the program (fuel was added only if it was felt that the tank level was so low that the preconditioning cycle could not be run), it is not necessary (and incorrect) to apply the MOBILE-based adjustment, which accounts for the difference between the 40% fill level on the FTP and an average 55% fill level observed in-use. In addition, the adjustment to a 95°F basis using the existing MOBILE5a equation assumes that no revisions to this equation are necessary for MOBILE6. Because additional data have been collected on hot soak emissions under varying temperature and Rvp conditions since the release of MOBILE5a, it is inappropriate to ignore these data and assume that the MOBILE5a temperature adjustments are correct.

Finally, a regression analysis was performed to determine the Rvp coefficient in the existing MOBILE5a hot soak equation:

$$HS_{MOBILE5a} = \exp(A*(Rvp - 9.0) + B*(T - 82) + C)$$

The coefficient B was unchanged from MOBILE5a in this analysis because all hot soak data were adjusted to a 95°F basis prior to running the regression, and the coefficient C was unchanged because ARCADIS wanted to ensure that the existing MOBILE5a hot soak emissions estimates were unchanged for Rvps greater than 9. (There is no explanation given as to why they insisted on this condition.) The existing MOBILE5a and proposed MOBILE6 hot soak equations for pressure failures are compared below.

$$HS_{MOBILE5a} = \exp(0.413356*(Rvp - 9.0) + 0.05114*(T - 82) + 1.774)$$

$$HS_{MOBILE6} = \exp(0.4443*(Rvp - 9.0) + 0.05114*(T - 82) + 1.774)$$

The overall result of this analysis is that hot soak emissions from pressure test failures changed only slightly relative to MOBILE5a predictions, with the proposed MOBILE6 estimates being slightly higher than the MOBILE5a estimates. However, this is primarily a result of a poor choice of methods to perform the analysis. There is no reason to establish the constraint that the estimates from the real-world data have to be equal to MOBILE5a predictions at 9 psi Rvp. Recall also that the database ARCADIS analyzed consisted of non-real-world data as well, which should not have been included in the analysis.

Purge Test Failures - Purge test failures were analyzed in the same fashion as the pressure test failures described above. Again, all vehicle technologies were combined, and the hot soak test results were adjusted to a 95°F basis using the existing MOBILE5a equation. In addition, the fuel tank level adjustment factor of 0.88 was applied to all fuel-injected vehicles. As with the pressure test failures, ARCADIS established the constraint that the revised estimates had to match the MOBILE5a predictions at 9 psi Rvp. The results of this evaluation indicated a moderate decrease in hot soak emissions for failing purge vehicles relative to MOBILE5a at Rvp levels less than about 8 psi.
The same concerns as outlined above for the pressure test failures apply to this analysis of purge test failures.

Vehicles Passing the Pressure and Purge Tests - For pressure/purge passing vehicles, the data were stratified by fuel delivery technology – carbureted, TBI, and PFI. In addition, where enough data were available, the data were further stratified by vehicle class (i.e., light-duty vehicle versus light-duty truck). Finally, a distinction was made between 1981 to 1985 model-year vehicles and 1986 and later model-year vehicles.

Once the data were stratified according to these groupings, the same approach outlined above for pressure and purge failing vehicles was applied to the data. The hot soak test results were adjusted to a 95°F basis using existing MOBILE5a hot soak temperature correction factors (which, as described in Sierra's report on real-world emissions, have not changed since MOBILE4), the fuel-injected vehicles were (incorrectly) adjusted for "in use" tank level, and regressions were run based on the constraint that the hot soak value at 9.0 psi Rvp (and all temperatures) had to match MOBILE5a predictions. Note that the form of the MOBILE5a equation for pressure/purge passing vehicles is slightly different from that for failing vehicles, consisting of two components – a hot soak prediction as a function of Rvp and a temperature correction that is applied to the hot soak prediction:

$$HS_{\text{M5a-P/P Pass}} = (A + B*Rvp) * (C*Temp)/D$$

The temperature correction above (i.e., the term with the constants C and D) was developed for MOBILE5a such that the temperature correction factor is 1.0 at 82°F.

The results of the above evaluation were mixed. For TBI vehicles, the draft MOBILE6 predictions at Rvps less than 9.0 psi fell below the MOBILE5a estimates, while the draft MOBILE6 predictions for carbureted and PFI technologies fell above the MOBILE5a estimates. In fact, for the LDV PFI group (which is the most important category in terms of emissions forecasts), the regression analysis resulted in a negative coefficient for the Rvp term (i.e., "B" in the above equation). This result implies that the impact of lowering Rvp is to increase hot soak emissions. To "correct" this "intuitively incorrect" situation, ARCADIS used one of the most absurd techniques that we have ever come across. Instead of recognizing that the database they were analyzing was not appropriate for determining Rvp effects, ARCADIS simply added 25 “data points” to the regression analysis for 1986 and later model-year LDVs. These added data points were calculated from the existing MOBILE5a equation at 9 psi Rvp and 95°F, and including them in the analysis resulted in a positive B coefficient. No explanation is given in the report as to how it was concluded that 25 fabricated “data points” was the correct number to add to the analysis. Further, no justification was given to support the use of this unusual approach. In our opinion, this entire analysis is flawed and without merit.

Comparison to MOBILE5a - The draft MOBILE6 hot soak emission rates are compared to the existing MOBILE5a hot soak emission rates in Figure 1 (attached) for 95°F over Rvp values ranging from 6 to 9 psi. The pressure and purge failures shown in Figure 1 reflect all 1981 and later model years and all fuel delivery technologies. The results for the pressure and purge passing vehicles reflect 1986 and later model-year PFI light-duty vehicles. As noted above, the existing MOBILE5a hot soak rates are assumed to remain valid for Rvps above 9 psi.

As observed in the figure, the largest difference between the draft MOBILE6 estimates and the MOBILE5a estimates (on a percentage basis) is for the pressure/purge passing vehicles, while the pressure failure and purge failure estimates are relatively close. However, the methodology used to generate the MOBILE6 estimates cannot rationally be supported, particularly for the pressure/purge passing vehicles. Because of the constraint that the MOBILE5a and draft MOBILE6 estimates had to match at 9.0 psi Rvp, relatively close agreement between the two estimates was expected.

Alternative Approach

As noted above, the analytical methodology developed by ARCADIS to prepare estimates of hot soak emissions for MOBILE6 has serious flaws. Because the “real world” data that make up most of the hot soak test results were collected over a fairly narrow Rvp range (see Figure 2), those data cannot be used with any confidence to generate hot soak emissions as a function of Rvp. Variations as a result of Rvp differences are totally confounded with the individual vehicle variations – there was no systematic variation of Rvp in that program. Instead of the approach taken by ARCADIS, it is more appropriate to use the real-world data to develop revised baseline hot soak rates, and then use data collected in a more systematic test program (i.e., individual vehicles tested over a range of Rvps and temperatures) to develop corrections for temperature and Rvp. The discussion that follows presents an alternative methodology to develop revised base emission rates and revised temperature/Rvp factors for hot soak emissions.

Baseline Hot Soak Emission Rates - Mean hot soak emission rates from the Auto/Oil and EPA test programs are summarized in Table 1 for vehicles that were identified as non-liquid leakers. The model-year stratification is consistent with the recommendations made by ARCADIS, but results for LDVs and LDTs are combined for pre-1986 model years and for 1986 and later carbureted vehicles. This was done because of the small sample sizes within these groups. In addition, results for pressure/purge passing vehicles are reported separately from failing vehicles, consistent with the methodology that is apparently planned for MOBILE6. Note, however, that Sierra previously provided a detailed discussion of the problems associated with continued reliance on pressure and purge status when modeling hot soak emissions in the MOBILE model.* In that discussion, it was suggested that an emitter-category approach was more appropriate. We continue to believe that is the case and have performed the analyses that follow based on pressure/purge status only because it appears that EPA will continue to use that methodology in MOBILE6.

As observed in Table 1, the mean temperature of the testing performed in the real-world programs was approximately 98°F, and the mean Rvp was approximately 6.5 to 6.6 psi.

Table 1
Mean Hot Soak Emissions from Vehicles in the Auto/Oil and EPA Real-World Test Programs (Vehicles Without Liquid Leaks)

Pressure/ Purge	Model Year	Vehicle Class	Fuel Inj.	Sample Size	Mean Temp (°F)	Mean Rvp (psi)	Hot Soak (g/test)
Pass	81-85	LDV+LDT	Carb.	38	97.7	6.6	2.13
		LDV+LDT	PFI+TBI	32	98.4	6.5	0.53
	1986+	LDV+LDT	Carb	47	98.5	6.6	1.24
		LDV	TBI	54	99.8	6.6	0.48
			PFI	180	98.6	6.5	0.68
		LDT	TBI	25	96.3	6.5	0.41
			PFI	33	95.9	6.8	0.98
Pressure Fail[a]	All	All	All	32	99.1	6.5	3.49
Purge Fail	All	All	All	19	99.9	6.5	4.47

[a] Pressure test failures include vehicles that failed both the pressure test and the purge test.

It is proposed that these values (once corrected to a standardized temperature and fuel volatility level, as described below) be used to reflect revised baseline hot soak emission rates for the MOBILE6 model.

<u>Temperature/Rvp Corrections</u> - As noted above, the hot soak data analyzed by ARCADIS included a number of vehicles that were tested over a range of temperatures and Rvp levels. In addition to those vehicles, EPA had previously collected hot soak data over varying Rvps and temperatures. Those data, which were collected in 1995 and included vehicles through the 1994 model year, were obtained from EPA's emission factors database (in the "EV95" project) for use in the alternative analysis.

A summary of the data used here for assessing Rvp and temperature effects is contained in Table 2. Note that these data reflect fuel Rvp levels of 9.0 psi and below, which is important from the perspective that the existing Rvp/temperature corrections in MOBILE5a (which were developed for MOBILE4 and MOBILE4.1) were based on limited data for Rvp levels below 9.0 psi. There are 51 vehicles (1981 and later model years) and 326 tests in the "low" Rvp database that Sierra analyzed for this study; 44 of these vehicles are in the 1986 and later model-year group. (Note that additional hot soak data were collected by EPA just prior to the release of MOBILE5a at Rvp levels of 9.0 and 7.0 at temperatures of 80, 95, and 105°F; however, those data were not readily available for use in this analysis.)

Table 2
Distribution of "Low" Rvp Hot Soak Tests

Rvp	80°F	95°F	105°F
6.1-6.3	11	22	21
6.5-6.9	39	41	43
8.6-9.0	53	52	44

Although this database is an "unbalanced" set, i.e., not all vehicles were tested on all combinations of temperatures and fuels, there are methods to account for this. For this sample analysis, we used the SAS "ABSORB" command within a regression analysis to account for vehicle-to-vehicle variability and the unbalanced nature of the database. This is similar to the approach used in the Complex model in which each vehicle was assigned a dummy variable. The data were fit with the following equation, which is similar in form to the current MOBILE5a hot soak predictive equations for pressure and purge test failing vehicles:

$$\ln(\text{Hot Soak}) = A + B*(\text{Rvp} - 7.8) + C*(\text{Temperature} - 90)$$

The values of 7.8 psi for Rvp and 90°F for temperature were used because they reflect the mean values of the low-Rvp database.

To illustrate how this approach could be applied, three separate regressions were run for this sample analysis, based on technology and pressure/purge status:

- 1986 and later PFI vehicles passing the pressure and purge tests;
- 1981 and later vehicles failing the pressure test (passing or failing purge); and
- 1981 and later vehicles failing the purge test (but passing pressure).

The complete results of the regression analysis are given in Attachment A to this memo, and a summary of the results is contained in Table 3. As observed in Table 3, the coefficients for Rvp and temperature (i.e., B and C, respectively, in the above equation) are significant at the 99% confidence level for all three regressions.

Table 3
Summary of Regression Results for Proposed Hot Soak Temperature and Rvp Corrections

Pressure/ Purge	Parameter	Coefficient	t-statistic	Pr>|T|
Pass	Rvp	0.244	2.63	0.0107
	Temperature	0.069	6.73	0.0001
Pressure Fail[a]	Rvp	0.498	5.94	0.0001
	Temperature	0.069	7.32	0.0001
Purge Fail	Rvp	0.460	5.58	0.0001
	Temperature	0.060	6.54	0.0001

[a] Pressure test failures include vehicles that failed both the pressure test and the purge test.

Application of Rvp/T Regression Results to the Real-World Data - Using the results of the regression analysis, a multiplicative Rvp/Temperature correction factor can be applied to the real-world baseline hot soak emission rates contained in Table 1 to put all data on a consistent basis. We selected a temperature of 100°F and an Rvp of 6.5 psi as the "baseline" conditions for the real-world dataset because these values are near the mean for that entire database. The correction was based on the following:

$$HS_{6.5psi/100^\circ F} = HS_{Rvp/T} \times \exp(B*(6.5 - 7.8) + C*(100 - 90)) / \exp(B*(Rvp - 7.8) + C*(Temperature - 90))$$

As an example, assume that a vehicle passing the pressure/purge test had emissions of 0.30 grams/test at an Rvp of 6.3 psi and a temperature of 95°F. To correct this to a 6.5 psi/100°F basis, the following calculation is performed:

$$HS_{6.5psi/100^\circ F} = 0.30 \text{ g/test} \times \exp(0.244*(6.5 - 7.8) + 0.069*(100 - 90)) / \exp(0.244*(6.3 - 7.8) + 0.069*(95 - 90))$$

$$HS_{6.5psi/100^\circ F} = 0.30 \text{ g/test} \times 1.48 = 0.44 \text{ g/test}$$

This adjustment was applied to each data point in the real-world database, and the means were recalculated. This resulted in the following values:

- 1986+ PFI vehicles passing P/P = 0.62 g/test at 6.5 psi and 100°F;

- 1981+ vehicles failing pressure = 3.95 g/test at 6.5 psi and 100°F; and
- 1981+ vehicles failing purge = 5.47 g/test at 6.5 psi and 100°F.

Once the real-world means are recalculated to reflect 6.5 psi and 100°F, those results can be adjusted for user-input values of Rvp and temperature as follows to generate fleet-average hot soak emissions estimates as a function of fuel volatility and temperature:

$$HS_{Rvp/T} = HS_{6.5psi/100^{\circ}F} \times \exp(B*(Rvp - 7.8) + C*(Temperature - 90))/\exp((B*(6.5 - 7.8) + C*(100 - 90))$$

The results for the 1986+ model year, PFI, pressure/purge passing group are shown in Figure 3 for 90°F and in Figure 4 for 100°F. As observed in Figure 3, the results at 90°F are similar when comparing the MOBILE5a estimates to Sierra's estimates. The draft MOBILE6 results, however, indicate a much smaller dependence on the fuel volatility level. This is not unexpected since ARCADIS had to add fabricated data points to get the curve to bend down at lower Rvp levels.

The 100°F results shown in Figure 4 reveal a significant difference between Sierra's results and those proposed for MOBILE6 and those used in MOBILE5a. That is because the MOBILE5a temperature corrections for pressure/purge passing vehicles (which have not been modified since MOBILE4) assume a relatively small temperature impact for PFI vehicles. On the other hand, the revised regressions performed by Sierra for this study indicate a stronger reliance on temperature. This is observed in Figure 5, which shows Sierra's proposed hot soak emission rates at a series of temperatures and Rvp levels. Because ARCADIS chose to keep the MOBILE5a temperature corrections (and applied the constraint that their revised hot soak estimates had to equal the MOBILE5a values at 9 psi Rvp), it is not surprising that Sierra's estimates deviate significantly from those prepared by ARCADIS. A good cross-check of the validity of the various estimates is given in Figure 4. The mean hot soak emission rate for this set of vehicles from the real-world database (prior to correction to 6.5 psi Rvp and 100°F) shown in the figure corresponds well with Sierra's estimates (and it should), while both ARCADIS and MOBILE5a are under-predicting hot soak emission rates at this temperature and Rvp.

A comparison of results for pressure test failures is given in Figure 6, while Figure 7 contains the comparison for purge test failures. (Both figures are based on an ambient temperature of 90°F.) As seen in Figure 6, hot soak estimates from the real-world data are lower than those contained in MOBILE5a, but the shape of the Rvp effect is similar. Figure 7 shows that Sierra's estimates are almost exactly equivalent to MOBILE5a for purge test failures at 90°F.

Summary

Our review of EPA's proposed hot soak emission rates for MOBILE6 revealed serious problems with the methodologies employed by ARCADIS to generate revised hot soak emission rates from the real-world databases. Most notably, the fabrication of data points and the constraint that MOBILE5a emission rates must remain unchanged at 9.0 psi Rvp are of significant concern. As noted above, alternative analytical methods were proposed by Sierra that result in a closer match between the modeled results and the real-world data. It should be noted, however, that Sierra's proposal is not complete (e.g., not all technology groups were analyzed and not all available data were used in the revised Rvp/T correction factor analysis). Nonetheless, the general approach offers a substantial improvement over that proposed by EPA for MOBILE6.

Figure 1

MOBILE5a vs. Draft MOBILE6 Hot Soak Emissions Estimates
1986 and Later Model Year PFI Vehicles

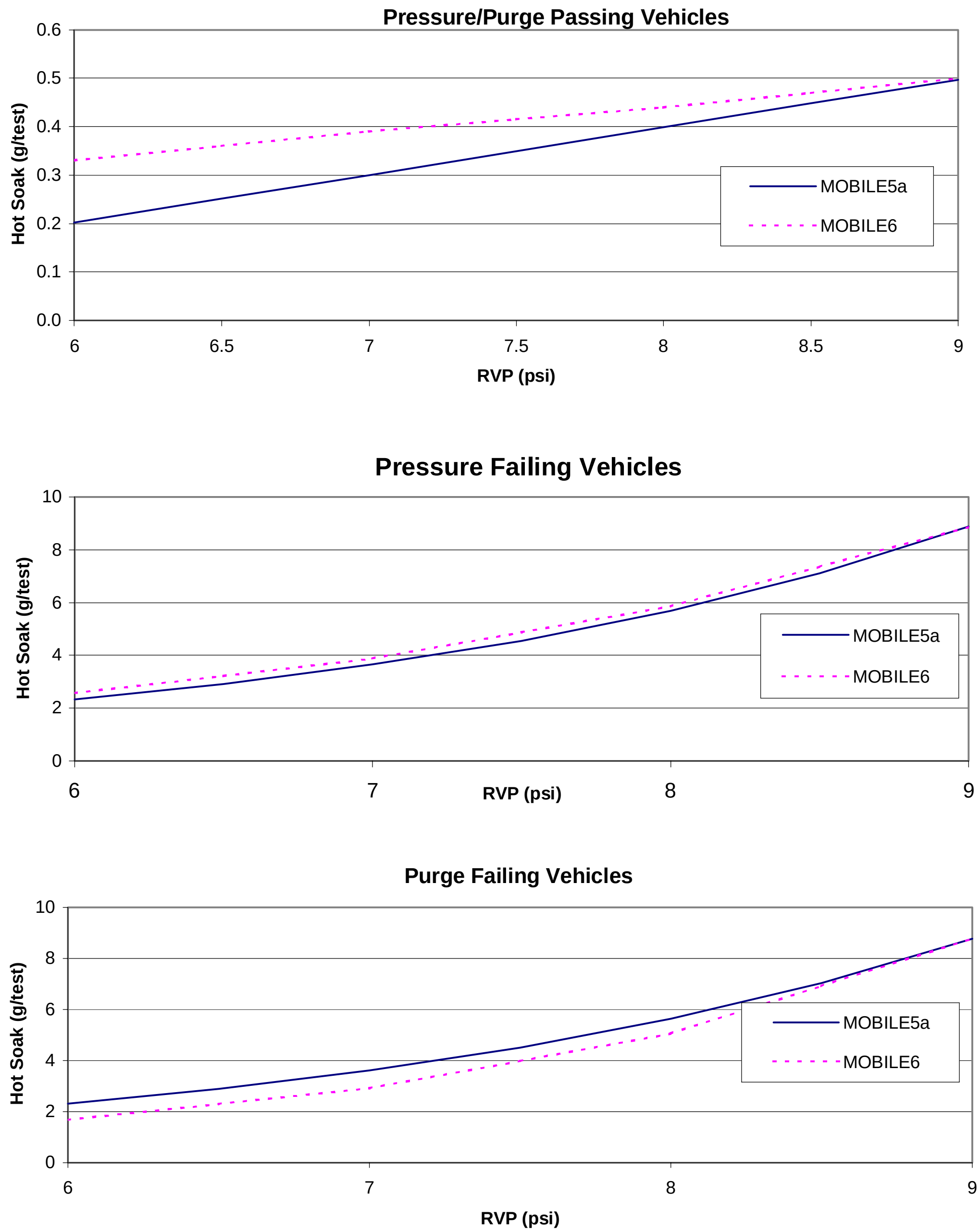


Figure 2

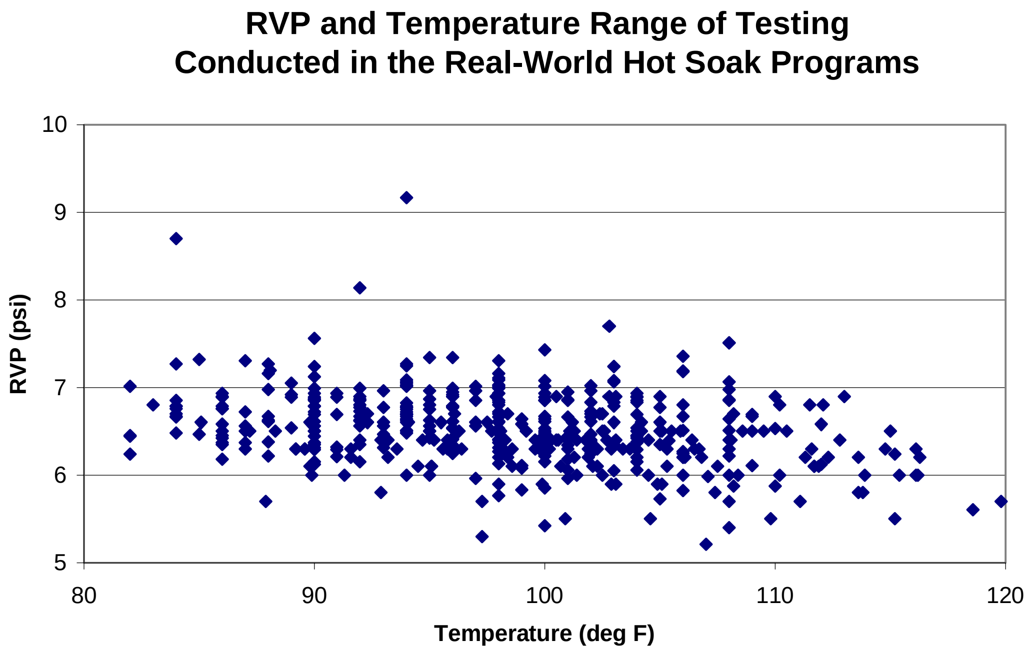


Figure 3

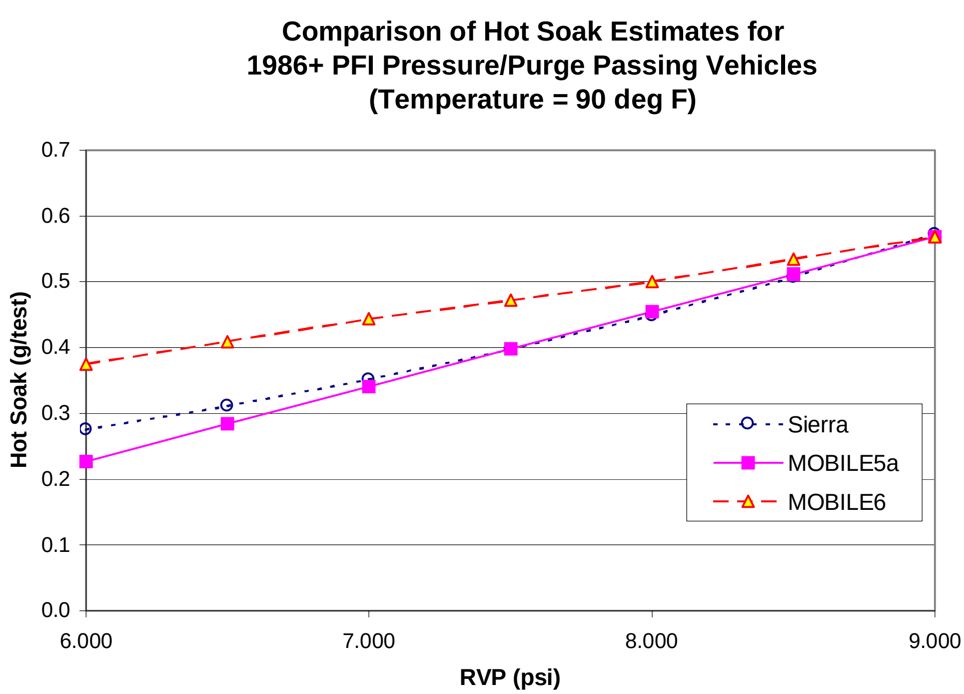


Figure 4

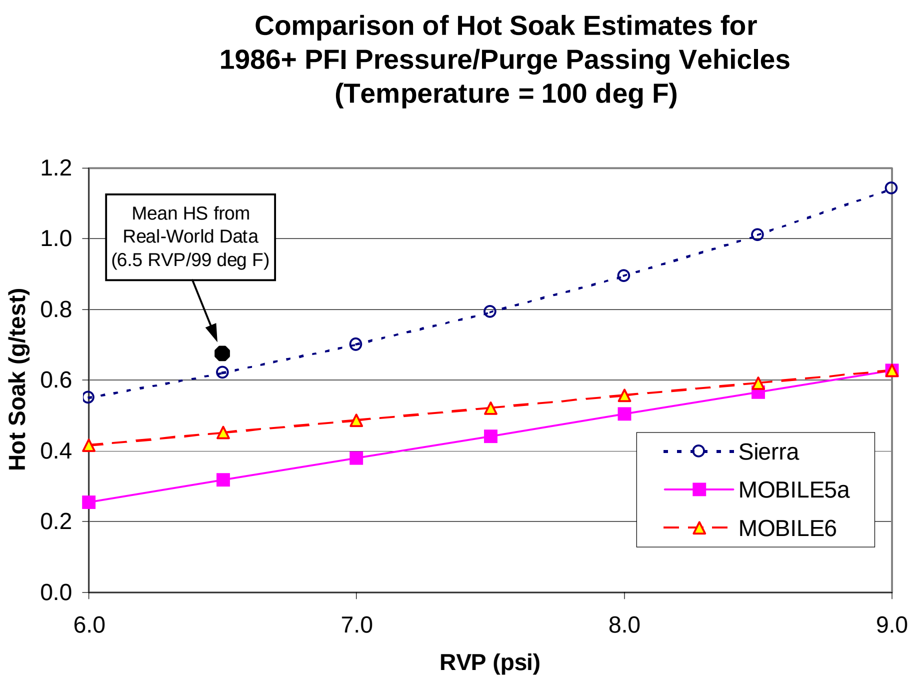


Figure 5

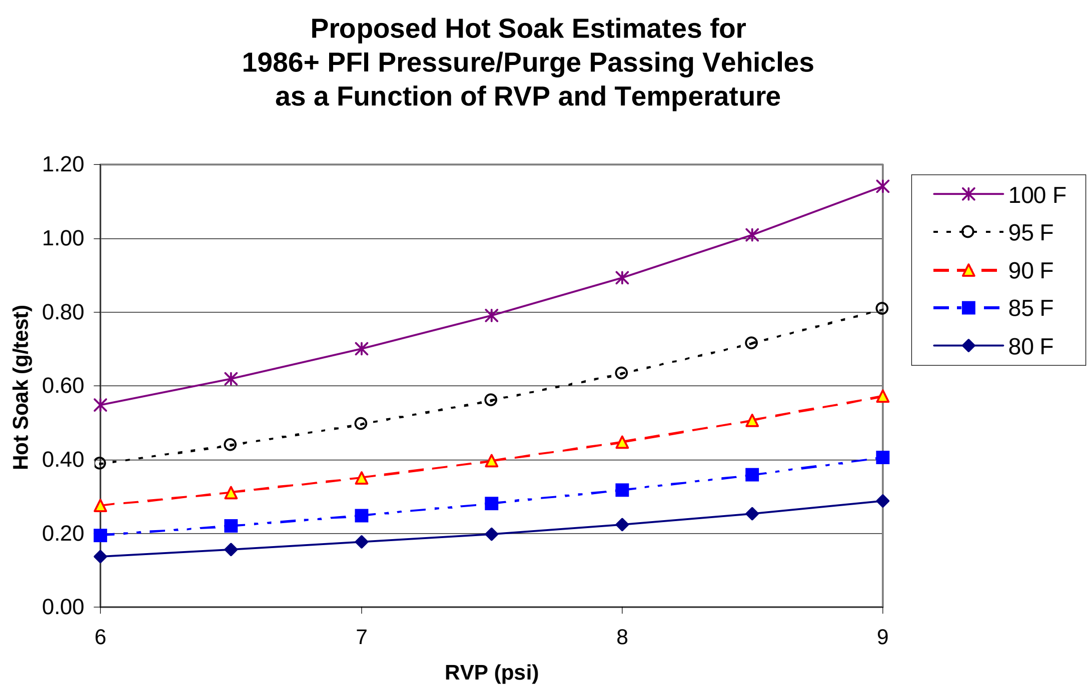


Figure 6

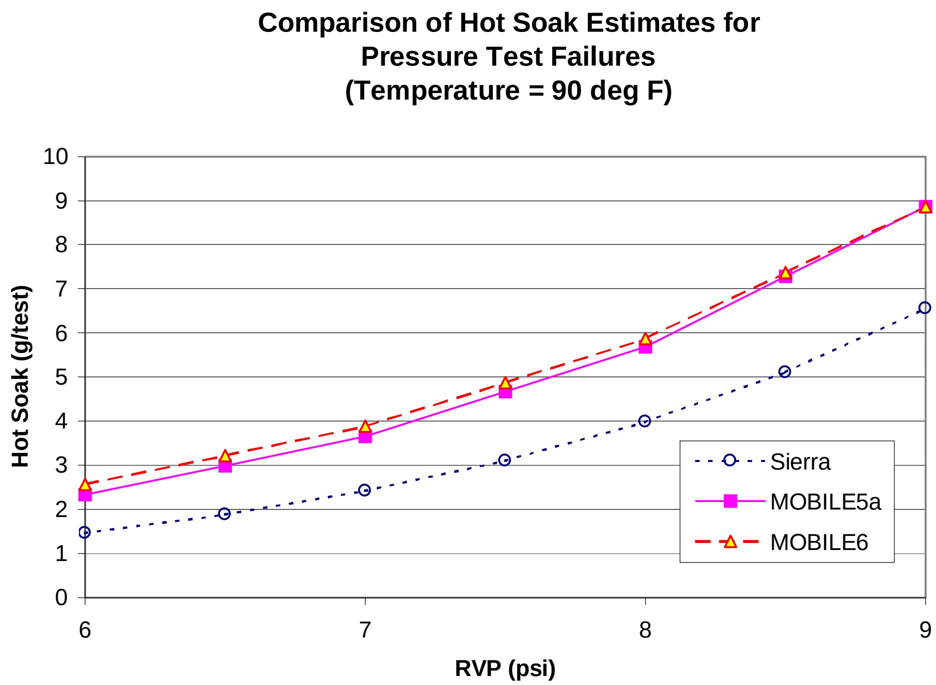
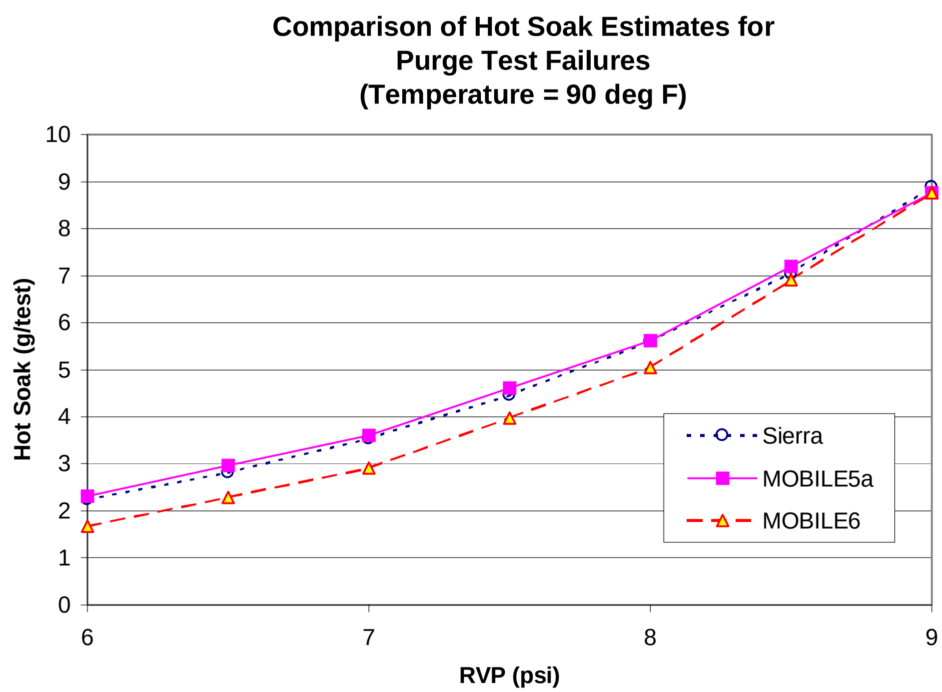


Figure 7



Attachment A

Regression Results for Sierra's Revised Hot Soak Rvp and Temperature Correction Factors

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[*] "Analysis of Real-Time Evaporative Emissions Data," prepared by Sierra Research for the American Petroleum Institute, Report No. SR97-12-01, December 10, 1997.

[**] Some vehicles in the EPA "real world" study were actually tested twice. However, the only difference in that testing was related to preconditioning procedures, which gives no information on temperature and Rvp effects. In addition, a number of vehicles in both programs were repaired and re-tested.

[*] "Analysis of Real-Time Evaporative Emissions Data," Prepared by Sierra Research for the American Petroleum Institute, Report No. SR97-12-01, December 10, 1997.

[*] In particular, it appears that the supplemental data provided by EPA included 17 vehicles that were tested over a number of temperature and Rvp combinations to generate 102 data points (i.e., each of these vehicles averaged 6 tests).

[**] D.J. Brooks, et. al., "Real World Hot Soak Evaporative Emissions – A Pilot Study," SAE Paper No. 951007, 1995.

[*] The Bernoulli equation relates the pressure, velocity, and elevation between two points in a flow field for <u>steady flow</u> conditions (Roberson and Crowe, <u>Engineering Fluid Mechanics</u>, Houghton Mifflin Co., Boston, 1980). A leak of this type could not be considered steady flow (particularly after engine shut-down), and therefore application of the Bernoulli equation is not appropriate.

[**] "Raw Fuel Leak Survey in I/M Lanes," prepared by Automotive Testing Laboratories for the American Petroleum Institute and the Coordinating Research Council, June 10, 1998.

[*] "Analysis of Real-Time Evaporative Emissions Data," prepared by Sierra Research for the American Petroleum Institute, Report No. SR97-12-01, December 10, 1997.

General Linear Models Procedure

Number of observations in data set = 73

General Linear Models Procedure

Dependent Variable: LOG_HS

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	13	140.69449722	10.82265363	14.48	0.0001
Error	59	44.10350049	0.74751696		
Corrected Total	72	184.79799771			

R-Square	C.V.	Root MSE	LOG_HS Mean
0.761342	-167.1792	0.86459063	-0.51716413

Source	DF	Type I SS	Mean Square	F Value	Pr > F
PROJ	3	37.61645876	12.53881959	16.77	0.0001
VEH(PROJ)	8	66.54258964	8.31782370	11.13	0.0001
D_RVP	1	2.72511589	2.72511589	3.65	0.0611
D_TEMP	1	33.81033293	33.81033293	45.23	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
D_RVP	1	5.18967501	5.18967501	6.94	0.0107
D_TEMP	1	33.81033293	33.81033293	45.23	0.0001

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
D_RVP	0.2438043402	2.63	0.0107	0.09252985
D_TEMP	0.0692401419	6.73	0.0001	0.01029541

General Linear Models Procedure

Number of observations in data set = 89

General Linear Models Procedure

Dependent Variable: LOG_HS

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	16	182.10156341	11.38134771	14.89	0.0001
Error	72	55.04284560	0.76448397		
Corrected Total	88	237.14440902			

R-Square	C.V.	Root MSE	LOG_HS Mean
0.767893	90.88813	0.87434774	0.96200434

Source	DF	Type I SS	Mean Square	F Value	Pr > F
PROJ	3	35.70579304	11.90193101	15.57	0.0001
VEH(PROJ)	11	85.97743821	7.81613075	10.22	0.0001
D_RVP	1	19.40286443	19.40286443	25.38	0.0001
D_TEMP	1	41.01546773	41.01546773	53.65	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
D_RVP	1	26.96759829	26.96759829	35.28	0.0001
D_TEMP	1	41.01546773	41.01546773	53.65	0.0001

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
D_RVP	0.4979756381	5.94	0.0001	0.08384384
D_TEMP	0.0690408754	7.32	0.0001	0.00942577

General Linear Models Procedure

Number of observations in data set = 113

General Linear Models Procedure

Dependent Variable: LOG_HS

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	18	363.93953677	20.21886315	20.88	0.0001
Error	94	91.01266332	0.96821982		
Corrected Total	112	454.95220009			

R-Square	C.V.	Root MSE	LOG_HS Mean
0.799951	116.4993	0.98398162	0.84462437

Source	DF	Type I SS	Mean Square	F Value	Pr > F
PROJ	3	44.05071004	14.68357001	15.17	0.0001
VEH(PROJ)	13	252.76067312	19.44312870	20.08	0.0001
D_RVP	1	25.76604988	25.76604988	26.61	0.0001
D_TEMP	1	41.36210373	41.36210373	42.72	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
D_RVP	1	30.17911988	30.17911988	31.17	0.0001
D_TEMP	1	41.36210373	41.36210373	42.72	0.0001

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
D_RVP	0.4599047064	5.58	0.0001	0.08237616
D_TEMP	0.0601184912	6.54	0.0001	0.00919801